A Study on User Acceptance of Error Visualization Techniques

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ABSTRACT

Location-based services in general require information about the position of certain objects. For instance, for a navigation service the position of the user needs to be known. This position is usually provided by a positioning system. However, it is typical for all positioning systems that they are not perfect. This means that the positions they produce inherit position errors. Nowadays, usually only the position estimate is shown to the user even though a quality measure for the position error is provided by most positioning systems. To increase the user's trust in location-based services and the usefulness of these services, the user should be informed about the uncertainty of position estimates as well. Thus, in this paper we investigate different visualization methods for the position and the position error. We carried out a user study to obtain information about the usefulness of the different methods. For this, we developed a questionnaire that contains nine different position and position error visualization methods. Furthermore, the questionnaire covers four typical application scenarios to be able to investigate whether users prefer different visualization methods for different applications. The results indicate that users are indeed interested in the position error they have to face. Further, they prefer a simple in-map representation of the position and the position error. These results are constant over different applications.

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: [User-centered design]; H.5.2 [**User Interfaces**]: [Evaluation/methodology]

General Terms

Design, Experimentation, Human Factors

Keywords

context-aware computing, pervasive computing, location based services, positioning error, information visualization, user study

1. INTRODUCTION

During recent years the rate of people using cellular phones and other mobile telecommunication devices such as personal digital assistants (PDAs) has rapidly increased. In Germany for example in May 2007 already more than 80% of all households owned at least one cellular phone [6]. While this number is expected to grow even more in the years to come, also the functionality these mobile devices offer is steadily increasing.

Most of the recently introduced PDAs and cellular phones nowadays are equipped with – often multiple different – advanced networking technologies (e.g., GSM, UMTS, IEEE 802.11). Additionally to their use for data- and voice-communication, many of these mobile devices also feature one other interesting function. They offer the possibility to estimate the user's position. To accomplish this task, most devices use the satellite-based *Global Positioning System* (GPS) but also a few other techniques to estimate a user's position can be found. For example, the recently published iPhone manufactured by Apple Inc. [17] offers the possibility to estimate a user's position based on the signatures of 802.11 networks in the proximity of the device. A similar feature is also scheduled for upcoming releases of Symbian-based cellular phones equipped with 802.11 [18]. Opposed to GPS, the 802.11-based positioning approaches have the advantage to also work inside of buildings where GPS often is not operational due to the strong attenuation of the signals.

From a user's perspective, lots of new and exciting applications become possible by taking ones own and other peoples location into consideration. One application for example, that mainly helped GPS to achieve its current dominance in the outdoor sector, is navigation. In the past, people had to deal with road maps and take care to not lose their current location especially while they were driving a car. Nowadays this is no longer necessary as navigation devices that easily take over these tasks are affordable and commonly integrated in most new cars.

One key driver for the success of such navigation devices is the easy access to and control of the required information. The devices can be easily operated and the requested navigation information is displayed on large often touch-sensitive color displays. To give the user navigation instructions, voice output as well as an arrow or a colored path on the map is used in most devices.

While this kind of visualization seems reasonable for plain navigation, still one drawback remains. While operating under optimal conditions, all the mentioned techniques used to estimate a user's position deliver precise results with a high accuracy of the estimated position. If the conditions are sub-optimal though – as it often is the case in reality – the positioning accuracy rapidly decreases. As a result of this decrease in accuracy the estimated positions can be far away from the user's real whereabout. If the user is not notified in such a case, the information delivered by the positioning system is no longer useful to him. Therefore many of the

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systems used to compute the user's position also offer the possibility to estimate the quality of the current position estimation.

If the user gains access to these quality measures in such a way, that he can easily determine the quality of the current position estimation, the usefulness of the system in general increases. Additionally, the user's trust in the system will also increase because he is notified that the currently estimated position might be errorneous in some kind. Even though the problem of handling possible errors is intrinsic to all systems that compute position estimates and display them to users, to our best knowledge no preferred method exists among these to also display the expected position error in some way.

We have only talked about systems used for navigation up to now. The same issue though also exists for other applications that use information about a user's position to augment their delivered service in a location-aware way. The class of these applications, of which navigation is a part of, is generally called "location-based services" (LBS) [12]. All LBSs have in common that they use position information in some way. But there still exist some criteria that are commonly used to subdivide these services again into two smaller groups [1, 7, 12, 16].

The first group is formed by the so-called *pull* services. If a user actively requests position-dependant information from a service in such a way that he formulates the query and waits until the answer is computed, this service is generally seen as a *pull* service. An example for such a service is a restaurant-finder application. Here the user supplies his current position to the service and requests information on restaurants in his proximity. The service then looks up restaurants that match this criterion and sends information about them back to the user.

If a user on the other hand subscribes for a certain service and is sent some position-dependant information at a later time and maybe based on other criteria, this is generally called a *push* service. In this case, an example would be a user who wants to be notified each time a Japanese restaurant is coming closer than fivehundred meters from where he currently is staying. Another already implemented example are the home-zones that many cellular service providers offer their customers. Here the user can make calls at a lower rate while he is in his home.

A second common criterion, that can be applied to LBSs, is the required positioning accuracy. While locating a book in a library shelf requires a very precise position estimation in the range of centimeters, for doing the same with a friend in a building generally an estimation of the correct room is sufficient [12].

As the targeted user of an LBS generally will not be specially trained to use a certain service, it is especially important to make any delivered information easily accessible and understandable for the user. The way an LBS displays information to its users should be:

- informative
- fast perceivable
- tailored to the selected application

Therefore, to get a clear impression on the user preferences regarding these features and how to visualize the expected error for a position estimate under different circumstances, we selected several different types of visualization techniques that are suitable to give a user an impression of a possible positioning error. Additionally, we chose four scenarios to discover variations in the users' preferences with respect to their current task or environment and then conducted a paper-based survey asking the users to rate the different visualization techniques with regard to the scenarios. .

The contribution of this paper now is threefold: Firstly, we give an overview over different possible types of position and position error visualization methods. Secondly, these visualization methods are evaluated for different application scenarios by an extensive user study. Thirdly, we present the results obtained from the user study and discuss practical implications for applications that are build around position information.

The remainder of this paper is structured as follows: In Section 2 we give a short overview over prior work related to the topic of this paper. We cover as well the area of positioning systems for in- and outdoor usage as also relevant literature regarding location-based services and information visualization. Section 3 introduces the different application scenarios as well as the presented position and position error visualization methods. Additionally, the structure of the questionnaire is discussed and an overview over the group of participants is given. Subsequently, we present the results of the survey in Section 4. Section 5 finally concludes the paper.

2. RELATED WORK

The development of positioning systems is still a very active topic in the research community. During the last decades, many systems have been proposed to estimate a user's position. Some of these systems use infrared light [19], some ultra-sonic pulses [20], or radio signals [10, 2, 8, 14, 11] to fulfill the task of position determination. All of these systems are mainly targeted at indoor usage and even if some alternative approaches exist to estimate a user's position outdoors, there is much less activity in this sector due to the predominance of the satellite-based GPS [9].

While many positioning systems available nowadays offer an average positioning accuracy suitable for most LBSs, the user almost always still has no information on the quality of the current position estimation. GPS for example, delivers positions with an error less than ten meters under good conditions. If the conditions worsen though, this error rapidly increases. Therefore the GPS standard defines a value that represents the dilution of precision (DOP) of the current position estimation [15]. This value is computed based on e.g., the geometrical setting of the used satellites and can give the users a hint on how reliable their estimated position currently is [13].

For other positioning techniques, there also has been noticable effort to develop algorithms to qualify the quality of the current position estimation. For systems that use the angle of arrival (AOA) of incoming signals for example, a metric similar to that of GPS has been proposed [5].

Giving the user of a positioning system feedback not only on his estimated position but also on the expected error has several important functions. It as well gives the user an impression on the current system status as it also allows him to stay in control of how to handle the information. This is exactly what context-aware systems should do according to Bellotti and Edwards [3]. These systems should for example inform their users "of current contextual system capabilities and understandings". Additionally, they should "provide feedback" and keep the user in control.

But even if the used positioning system offers information on the accuracy of the current position estimation, it still is in question how to present this information to the user in a suitable fashion.

This question of how to visualize a positioning error has alredy been an issue of research in the area of positioning systems. In [4] the participants of a study had to solve a certain task with the help of a positioning system. While some participants only saw their estimated position on a map, for others also a circle around their estimated position was displayed that represented the 99.9%-, 95%- or N%-percentile of the cumulative error distribution of the used

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positioning system. For all groups, the time to fulfill the task as well as several other values were measured and evaluated afterwards. It clearly came up that even the plain variation of the radius of a circle on a map based on the error distribution of the positioning system already makes a differnce in the users' performance solving their task.

3. THE SURVEY

Our survey was conducted at the University of Mannheim in Germany on several consecutive days in April 2008. This section describes the general conditions under which the survey took place, the structure of the questionnaire and the composition of the group of participants.

3.1 The Four Scenarios

To reveal possible variations in the users' preferences regarding the application background, we selected two *pull* and two *push* service scenarios for our questionnaire. Each pair of scenarios was again split into one scenario that requires a higher and one that requires a lower positioning accuracy.

The first scenario we selected is a person looking for a certain object inside of a storage building. The object is supposed to have the size of a shoe box. In this case, the user actively requests the location of a small object with respect to his own position, so this is an example for a *pull*-service. The second scenario consists of an automatic call-forwarding system installed in an office building that automatically reroutes incoming calls to the phone that is closest to the estimated position of the user. As the call-forwarding system in this case tries to locate the user, this is an example of a *push* service.

For scenarios three and four, we selected a friend-finder application. When using such an application, persons generally are looking for persons, which requires a far lower positioning accuracy than needed in the first two scenarios. We intentionally decided to select the same application scenario twice here, once from the perspective of a user trying to locate friends nearby (Scenario 3, *pull*) and once from the perspective of a user being located by a friend (Scenario 4, *push*). This was done to check whether possible privacy concerns have an influence on the users' preferences.

3.2 The Questionnaire

The questionnaire itself is composed of a short introduction and two out of our four scenario descriptions. Each scenario description is followed by the set of visualization examples. For each scenario, the participants had to rate each different error visualization technique in the categories:

- information content
- perception speed
- suitability for the selected scenario

We chose to split the four scenarios into two groups to reduce the size of the questionnaire. Even with only those two scenarios being inquired on each questionnaire, it already had a length of nine DIN A4 pages. One version of the questionnaire therefore contains scenarios one and four and the other version is made up of scenarios two and three.

Over all, the participants could rate nine different variants of describing and displaying the error. All the variants use the same underlying information about the position estimate and the expected positioning error for their visualization purpose. For two of the display variants, the possible error is directly displayed on the map that is also used to visualize the estimated position (see Figure 1). Hereby, in the first alternative, an area around the estimated position is marked based on the expected error. In the second alternative, rooms or larger sections of hallways are marked based on the estimated position and the expected error.

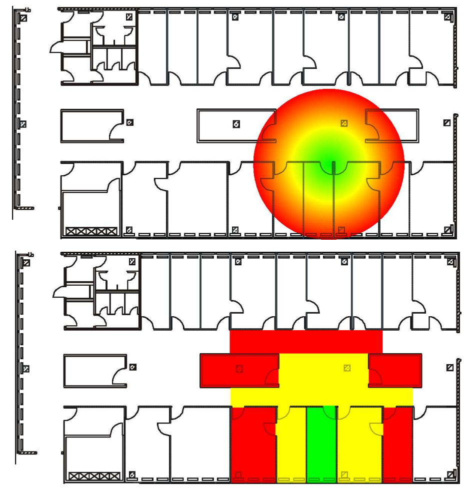

Figure 1: Visualization of the expected error directly within the map that is also used to visualize the estimated position.

Three of the nine display variants rely on displaying the possible error in a textual way. This is accomplished by either expressing the quality of the estimated position or the expected degree of the error in words or by displaying the size of the expected error as an absolute number (see Figure 2). For the latter of these three variants, the absolute number is just an example as in reality the achievable positioning accuracy greatly depends on the used positioning system.

Quality: "very good", "good", ..., "very bad"
or
Degree of error: "very small", "small", ..., "very large"
or
Absolute number: "Positioning error ≈ 3.4m"

Figure 2: Textual display variants for the expected error

Three other variants display the expected error in a graphical way next to the map on which the estimated position is shown. Hereby, one variant uses a stylized traffic light where the different colors are used to qualify the positioning accuracy (see Figure 3).

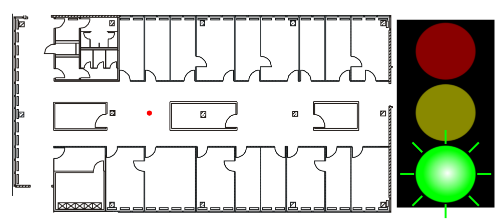

Figure 3: Graphical visualization of the expected error using a stylized traffic light

The other two use depicted analog gauges, one round and one as a bar, to visualize the estimated error (see Figures 4 and 5).

As a last display variant, the participants where offered the plot of a general cumulative error distribution of the underlying positioning system (see Figure 6).

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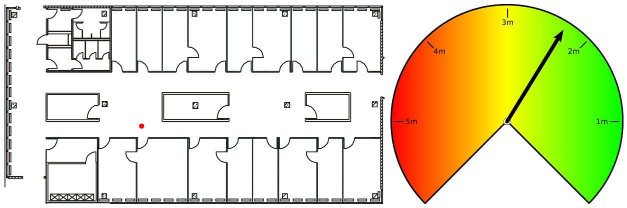

Figure 4: Graphical visualization of the expected error using an analog round gauge

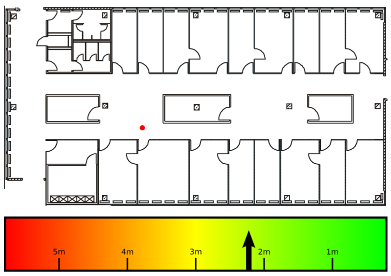

Figure 5: Graphical visualization of the expected error using an analog bar gauge

3.3 The Participants

To get a wide variety of participants, people all over the university campus were asked to take part in the survey. In total, 55 persons successfully completed the questionnaire. Among these, 28 persons were given scenarios one and four, the remaining 27 persons filled out a questionnaire containing scenarios two and three. From the 55 participants, 14 were female, 40 were male and one person did not disclose its gender. The participants had ages ranging from 17 years to 30 years.

About one third were students of computer science or related technical fields like software- and internettechnology and management information systems. Another third was composed of students of business administration, economics and related fields like business and human resource education. Finally, the last third of the participants indicated various other fields of study or work, for example philosophy, politics or process engineering.

All the 55 participants are somehow related to the University of Mannheim. Therefore, we expect that the results might be slightly different for a demographically more representative group of people.

4. RESULTS

In this section, we present the general results of our survey. We elaborate on the different scenarios as well as on differences between the genders, fields of study and the participants age.

4.1 The Four Scenarios

In contrast to our expectations, the examination of the survey results does not indicate any statistical relevant differences between the four scenarios in question. When comparing the results of the two *push* with those of the two *pull* scenarios, the users for example do not seem to be concerned about privacy issues (see Figure 7) and also do not make any statistical relevant difference regarding the object to be located.

Also somewhat surprising is that there seems to be no significant change in the participants' preferences between the scenario that appears first on the questionnaire and the one that is second (see

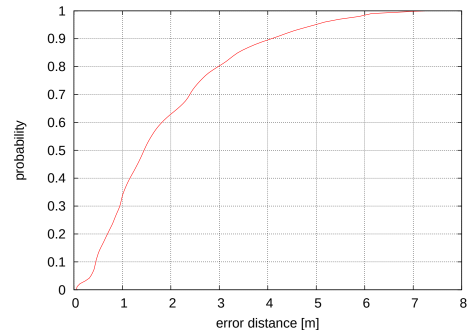

Figure 6: Cumulative error distribution

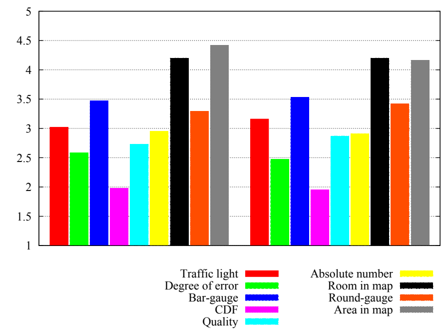

Figure 7: The results of the two pull scenarios (left) compared to those of the two push scenarios (right) regarding the suitability of the error visualization techniques

Figure 8). The comments that some participants made on our questionnaire about the order of the alternatives stated that for the first scenario, the order of the different visualization possibilities generally is important. As the participant does not know what other possibilities are still to come, he will usually not use the full bandwidth of possible answers in the beginning. For the scenario that is at the second position in the questionnaire, the participant has already an impression of all the different alternatives and should therefore show a learning effect. Despite the received comments, we though were not able to find any indication in our data, that would support this expectation. It rather seems, that even people with a non-technical background nowadays have an at least vague idea on how a positioning system with or without error visualization should look like and therefore show no learning effect.

4.2 General Results

As the results of the single scenarios do not differ in a statistical relevant way, we chose to evaluate the results for all four scenarios together for the remainder of this section.

4.2.1 Suitability

The first feature that the participants of our survey had to rate is the suitability of the error display variant for the current scenario. Each variant could be rated from greatly unsuitable (1) up to greatly suitable (6).

Regarding this feature, the results we obtained are quite unambiguous. On average, the people that took part in our survey generally prefer the visualization of the positioning error in conjunction with the estimated position together on one map. This map is shared for both types of information. The results also indicate a

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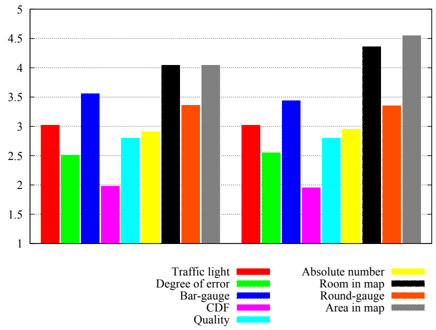

Figure 8: The results for the scenarios that were first on the questionnaire (left) compared to those in second position (right) regarding the suitability of the error visualization techniques

slightly higher acceptance of graphical visualization variants compared to textual ones. Finally, almost all participants rated the the cumulative error distribution (CDF) the worst, resulting in an average rating of very unsuitable (see Figure 9). While these results might be obvious when talking about visualization of a position estimate, they are not when talking about the visualization of an expected positioning error.

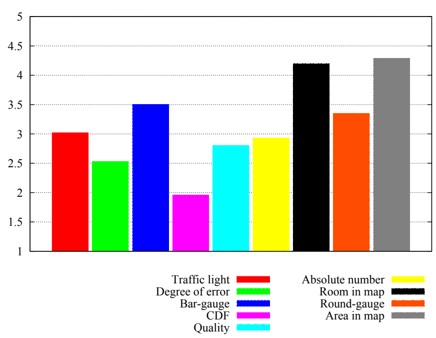

Figure 9: The average suitability rating for the different error visualization techniques

One interesting distinctive feature in this regard exists between men and women. While for all other display variants, the rating is very similar for men and women, the latter ones rate the CDF noticeable better than the male participants. The rating still is shortly above very unsuitable though, leaving the CDF the worst alternative.

Also worth to mention are the differences that show up when comparing different ages. We split our participants up into two groups. One group consists of the people below 24 years and the other group contains the people at the age of 24 or older.

For the second group, we find a clear dominance of the two in-map visualization techniques. While these two variants also take the lead for the group of younger people, their overall rating is lower. Also, the younger people rated the variant using the analog bar-gauge good instead of bad as the other group did.

We also separated the participants based on their field of study or work. One group is made up of people with a strong background in computer science like students of computer science itself or related fields. The second group consists of participants studying or working in the area of business administration, economics or other business related fields. The remaining people are grouped together in a third group.

We expected to find major differences at least between the group of people with a strong technical background and the two other groups. This is not the case though. On average, the people from the first group again rate the analog bar gauge slightly better than the people from the other two groups. But all other variations are to small to draw any further conclusion.

Even though, due to the small number of participants, we cannot statistically prove the general applicability of our results to a high degree of confidence, we still are convinced that they give a good impression on the users' preferences regarding the suitability of different techniques for visualizing an expected positoining error.

4.2.2 *Perception Speed*

Depending on the targeted application, it is important that the user is able to quickly get an impression of the displayed information. This is especially true if the user is performing other tasks that require his attention in parallel.

Therefore, we also asked the participants of our survey to rate the different display variants for the positioning error in terms of their perception speed. The possible options here were greatly slow (1), very slow (2), slow (3), fast (4), very fast (5) and greatly fast (6). Compared to the suitability, here we have a quite homogenous picture. Most display variants are rated fast or very fast. Only two of the text-based variants and again the CDF are rated slow respective very slow (see Figure 10).

We could not find indications for relevant differences between our male and female participants. Regarding the age, the differences between the two groups also are quite small and we therefore do not want to draw any conclusion here. But when we look at the groups that are composed based on the field of study, we can see some interesting results. The group of people with a computer science related background rates the two display variants that use the analog gauges noticeably better than the other two groups. This is especially true compared to the group of participants with a business related background. Here both of these display variants are rated slow compared to the ratings fast and very fast for the group of participants with a computer science background.

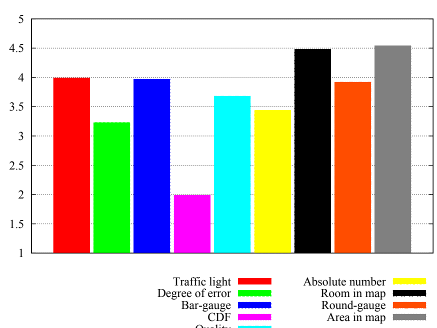

Figure 10: The average rating of the perception speed for the different error visualization techniques

4.2.3 *Information Content*

Finally, we asked the participants of our survey to rate the different methods to visualize the expected positioning error with respect to the information content of the respective variant. The results here might again be especially interesting when designing a system for a special purpose. While for some applications, a very precise in-

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formation perception might be necessary, for other applications the same could form an obstacle.

In terms of the information content, the evaluation of the survey shows that again the two variants that show the expected error together with the estimated position on the same map are rated the best. Both have an average rating of very high regarding the information content. While the two variants that use the analog gauges to display the expected error also are rated at least high, it is interesting that the same is also true for the numerical display variant. In contrast to this, the other two text based display variants are only rated low on average (see Figure 11).

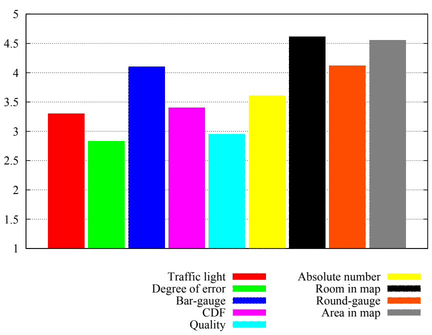

Figure 11: The average rating of the information content for the different error visualization techniques

One reason for the good rating of the numerical display variant is the group of the female participants. Compared to the male participants who clearly prefer the in-map display variants over the others, the female participants on average rate the numerical as well as the both in-map and analog gauge variants equally with high.

Looking at the age, we find a similar better rating for the numerical display variant. This though, seems to be the result of the very low number of females in the group of participants at the age of 24 or older. From the 14 female participants, eleven are 23 years old or below.

Also interesting is a very high difference in the rating of the CDF between the participants with a technical and those with a non-technical and non-business background. The first group rates the information content of the CDF with an average value of very high. The other group rates the same variant with an average value of low. In this case, it seems that the technical people have a better understanding of the information that such a CDF expresses.

5. CONCLUSIONS

Taking the results from our survey as well as the composition of the group of participants into consideration, we gathered interesting and novel results in how different visualization methods of the position and the estimated position error are conceived by people. This information is a valuable hint for designers of LBSs that require to visualize position information.

In our study, we could not identify major differences between the different types of application scenarios. We therefore are sure that the users of such systems either make no strong differentiation between different types of applications or have not yet developed a strong opinion in this regard. But this does not mean that the users do not have a general idea of what kind of visualization techniques they prefer. The participants of our study clearly favor the use of techniques that visualize an expected positioning error together with the estimated position on a map. They also object to the usage of a CDF independent of the scenario. We believe that the reasons here are twofold. First, even if a CDF has a high information content in general, it does not offer any situation specific information. Second, for many participants, it was hard to understand the exact meaning of the CDF in this use.

As the selection of scenario types we chose covers the main areas for LBSs, the minimal differences between the results of our four scenarios indicate an applicability of our findings for other scenarios as well.

We therefore suggest to anyone who develops an LBS and wants to not only visualize an estimated position to his users but also an expected positioning error to consider the different alternatives well. We in our case definitely will use in-map visualization techniques for our further developments in the are of indoor positioning systems.

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